Effects of sublethal avermectin and fipronil treatments to host *Plutella xylostella* larvae on growth and development of the parasitoid wasp *Cotesia plutellae*

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Abstract: Effects of insecticides on the cocoon formation and adult emergence in the field population of *Cotesia plutellae* were studied. Sublethal dosage of avermectin or fipronil was fed to the 2nd instar larvae of host *Plutella xylostella* (DBM), in which the parasitoid *C. plutellae* were at the egg, early and mid larval stages. When compared to the control, the cocoon formation of *C. plutellae* reduced by 26.6%, 22.8% and 5.8% if parasitized DBM larvae were fed on leaves treated with avermectin when the immature parasitoids were at the egg, early larval and mid larval stages, respectively, and by 76.9%, 42.5% and 18.5%, respectively if parasitized DBM larvae were fed on leaves treated with fipronil. No significant depression on the adult emergence of *C. plutellae* was found in avermectin treatment. However, the adult emergence of the parasitoid reduced by 53.1%, 36.1% and 47.8% at the egg, early and mid larval stages of the parasitoid in fipronil treatment. The results indicated that avermectin and fipronil, even at very low dosages ($= LC_{10}$ to the host insects), might still cause serious damage to the parasitoid's eggs or larvae. The effects of the insecticides on cocoon formation and adult emergence of *C. plutellae* varied depending on different insecticides and different developmental stages of the endoparasitoid.

Key words: *Cotesia plutellae*; avermectin; fipronil; sublethal dosage; cocoon formation; adult emergence

1 INTRODUCTION

Indiscriminate application of insecticides to a pest can eliminate its parasitoids and predators and exacerbate the pest problem. Parasitoid populations in the field are often largely suppressed as a result of indiscriminate application of insecticides. Efforts are now being made to search for alternative control measures. Biological control, along with the integration of chemical and biological control systems for arthropods by the use of integrated pest management-compatible pesticides became increasingly concerned in pest management programs (Villanueva-Jimenez *et al.*, 2000; Hill and Foster, 2000). It was identified that *Cotesia plutellae* (Hym.: Braconidae) had the greatest control potential among the parasitoids of *Plutella xylostella* (DBM) (Lep.: Yponomeutidae) in Fuzhou, China (Wu and Jiang, 2004). Many researches are aimed at the toxicity and selectivity of insecticides, such as organophosphates, carbamates, pyrethroids, fipronil, avermectin, benzoylphenyl urea compounds and *Bacillus thuringiensis* toxin formulation against DBM and its parasitoids (Haseeb *et al.*, 2004; Wu and Jiang, 2004; Shi *et al.*, 2004). However, the estimated lethal dose during acute toxicity tests may only be a partial measure of the deleterious effects. In addition to direct mortality induced by pesticides, their sublethal effects on arthropod physiology and behavior must be considered for a complete analysis of their impact. An increasing number of studies and methods related to the identification and characterization of the sublethal effects (including effects on learning performance, behavior, and neurophysiology) have been published in the past 15 years (Desneux *et al.*, 2007). The sublethal effects of insecticides on *C. plutellae* were reported (Talekar and Yang, 1991; Shi *et al.*, 2004). In addition, the cocoon formation of *C. plutellae* could be depressed when parasitized DBM were fed on sublethal dosage of fenvalerate (Li *et al.*, 2002), spinosad (Li *et al.*, 2005) and methamidophos (Lin *et al.*, 2007). Significant inhibitions of cocoon

基金项目: 科技部国际合作重点项目(05DFA30440) 国家自然科学基金项目(30771413)
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收稿日期 Received: 2007-04-20; 接受日期 Accepted: 2007-11-27

formation and adult emergence of *Diadegma semiclausum*, a larval parasitoid of DBM, were found when parasitized larvae of DBM were fed on avermectin (Iqbal and Wright, 1996). Laboratory selection for fenvalerate resistance of larvae DBM showed that parasitoid larvae could be exposed to insecticide selection via the hosts, selection with more resistant hosts could accelerate development of resistance in the parasitoid and resistance genes selected during larval development of parasitoid could be expressed at its adult stage (Li *et al*., 2002). *C. plutellae* can develop its resistance to insecticides in the field just as its host DBM. Significant development of resistance to methamidphos was found in *C. plutellae* (Wu *et al*., 2004). The evolution of insecticide resistance in parasitoids could be affected either directly by exposing to the spray in the field, or indirectly by insecticide penetration in the host (Iqbal and Wright, 1996; Wu *et al*., 2004; Lin *et al*., 2007).

However, the study on the development of endoparasitoids as affected by the sublethal insecticide dosages on their host larvae was limited, and the cases of avermectin in *C. plutellae* or fipronil in endoparasitoids could not be found yet. The present paper describes the cocoon formation and adult emergence of *Cotesia plutellae* as affected by the sublethal avermectin and fipronil on the larvae of DBM at different developmental stages of *C. plutellae*.

2 MATERIALS AND METHODS

2.1 Sources of insects

DBM and its parasitoid *C. plutellae* were collected from the commercial crucifer (*Brassica oleracea* var. *italica* L.) vegetable fields in Shangjie, Minhou, Fujian, China. The two insect species were collected when the climate was conducive to their development. The field-collected DBM pupae and *C. plutellae* cocoons were reared in an environmental chamber at 25℃ with a photoperiod of 16∶8 (L∶D) before the test. Newly emerged adults of DBM (F_0 parents) and *C. plutellae* (F_0 parents) were used to determine the susceptibility to the insecticides (Table 1). In Tables 2 and 3, F_1 progeny 2nd instar larvae of the field collected DBM and newly emerged *C. plutellae* (F_0 parents) were used to study the effects of sublethal insecticide on immature development of *C. plutellae*.

2.2 Chemicals

Avermectin (1.8% EC) was obtained from Shijiazhuang Insecticide Co., Ltd., Hebei, China; and fipronil (5% SC) from Rhone-Poulenc AG, France.

2.3 Determining the toxicity of insecticides to insects

A residual film technique was adopted for our bioassay of adult of *C. plutellae* and DBM (Shi *et al*., 2004). A volume of 2.0 mL insecticide solution in acetone was poured into a glass vial (1.2 cm diameter, 10 cm length), and capped by a rubber plug. The solution in vial was vibrated (swirled) for 10 s. Then, the excess solution was poured off vertically, and the treated vial was inverted on a wire rack. The residue was air-dried for 4 – 5 h to produce the dry film which covers the inner surface of the vials. After the solvent was fully evaporated, treated vials were used for the bioassay. Control vials were treated with acetone only. Newly emerged adults of *C. plutellae* and DBM were introduced into the vial and left in contact with the insecticide for 48 h. The vial was provided with a 15% honey solution for food. Each concentration was replicated three times, each with 15 individuals. The mortality was recorded at 48 h after treatment.

In addition, a leaf-dipping technique was adopted for the bioassay of 2nd instar larvae of DBM according to Wu *et al*. (2004). The test solutions of the insecticide formulation were prepared by dilution with water containing 0.02% Triton-X100 to make desired concentrations. *B. oleracea* leaves (5 cm × 5 cm) were dipped for 10 s in an insecticide solution and left to air dry at 25℃. The treated leaves were then introduced into a plastic cup (200 mL) and 15 2nd instar larvae of DBM were placed on each leaf. Each concentration was replicated three times. For the control, *B. oleracea* leaves were dipped in distilled water containing the spreading agent only. The mortality was recorded at 48 h after treatment. Larvae which did not respond to pencil tip prodding were judged to be dead. Each toxicity regression equation of each insecticide was calculated based on five concentrations and their corresponding mortalities done with about 150 larvae. LC_{10} and LC_{50} values were calculated based on the toxicity regression equation for 2nd instar larvae of DBM, respectively. The dosage at LC_{10} was used to feed the 2nd parasitized larvae of DBM.

2.4 Parasitized larvae of DBM were fed on insecticides on the first day after oviposition by parasitoid

It was reported that the developmental durations of *C. plutellae*'s egg and larval stage were about 2 – 3 and 7 – 8 days, respectively at 25℃ in environmemtal chamber (Ke and Fang, 1982). Therefore, it was defined in this study that the *C. plutellae* in the host larvae was at the egg stage, early larval stage and mid larval stage, respectively when parasitized larvae of DBM were fed on insecticide-treated leaves on the first,

3rd and 5th day after oviposition by *C*. *plutellae* at 25℃. In order to study the effects of insecticide treatment on the cocoon formation and adult emergence of *C*. *plutellae* when the parasitoids were at the egg stage of development, the method reported by Iqbal and Wright (1996) was used. An undamaged *B*. *oleracea* plant, which was 20 cm high and with 6 leaves, was planted in a big plastic cup with soil, and put in an environmental chamber at 25℃ with a photoperiod of 16∶8 (L∶D) for 2 days. Then, the leaves of the *B*. *oleracea* plant were dipped for 10 s in an insecticide solution and left to air dry at 25℃. The concentration of insecticide solution was produced at the LC_{10} value, which was calculated based on the toxicity regression equation of the insecticide for 2nd instar larvae of DBM. The pretreated *B*. *oleracea* plant was then transferred into a cage (20 cm diameter × 30 cm length) in an environmental chamber at 25℃ with a photoperiod of 16∶8 (L∶D). The cage was confined by a fine mesh nylon net and the bottom with a white plate. Twenty 2nd larvae of DBM with 6 h starvation were introduced into the cage and fed on the pretreated cabbage leaves for 2 h. These 20 larvae of DBM were then used to expose to parasitoids for oviposition. One pair of pre-mated male and female *C*. *plutellae* adult of was then introduced into the cage with pretreated *B*. *oleracea* plant and 20 larvae of DBM, and used for parasitoid's oviposition for 8 h. The pair of *C*. *plutellae* adults was then removed from the cage. The 20 2nd instar larvae of DBM in the cage were reared continuously on the pretreated *B*. *oleracea* plant until the pupae of DBM and the cocoon of *C*. *plutellae* were formed. Seven days later, the numbers of cocoon formation of *C*. *plutellae* were recorded daily until all the cocoon of *C*. *plutellae* were recorded. For each insecticide treatment, five replications were made. Thus, 100 2nd instar larvae of DBM for each insecticide were needed. The numbers of adult emergence of *C*. *plutellae* were also recorded based on the collected cocoon. For the control, *B*. *oleracea* leaves were dipped in distilled water containing the spreading agent only.

2.5 Parasitized larvae of DBM larvae were fed on insecticides on the third and fifth day after oviposition by parasitoid

In order to study the effects of insecticide treatment on the cocoon formation and adult emergence of *C*. *plutellae* when the parasitoids were at the early and mid larval stages, the method reported by Li *et al*. (2002) was used. A pair of male and female adults of *C*. *plutellae* was put in a vial. After *C*. *plutellae* had mated successfully, the female adult of *C*. *plutellae* was introduced into an another vial. Then, one 2nd instar larva of DBM was introduced into the vial to expose to parasitoid's oviposition in an environmental chamber at 25℃ with a photoperiod of 16∶8 (L∶D). As soon as the female *C*. *plutellae* had oviposited successfully one time (*i*. *e*., oviscapt pricked in the larva body one time), the parasitized larva of DBM was removed from the vial. Then, another 2nd instar larva of DBM was introduced into the vial for the oviposition by the same female adult of *C*. *plutellae* again. In total, 4 to 5 2nd instar larvae of DBM were exposed to oviposition by one female adult of *C*. *plutellae*. Then, another newly mated female was used for the parasitism. Twenty 2nd instar larvae of DBM were used for each experiment. The 20 parasitized 2nd instar larvae of DBM were introduced into a plastic cycle box (10 cm diameter × 30 cm length), and fed on a fresh *B*. *oleracea* leaf (non-insecticide-leaf) in the first three days. The leaf was kept moisture by cotton and aluminium foil. After the larvae DBM were fed on the fresh leaves for 3 or 5 days, the fresh *B*. *oleracea* leaf was removed from the box, respectively, and replaced by a leaf treated with insecticide. The treated leaf had been dipped in a solution of the insecticide for 10 seconds at LC_{10} dosage (sublethal dosage for 2nd instar larvae of DBM), and left to air dry at 25℃. For each insecticide treatment, six replications were made. Thus, 120 2nd instar larvae of DBM for each insecticide treatment were needed in total. The experiments were conducted in an environmental chamber at 25℃ with a photoperiod of 16∶8 (L∶D). For the control, *B*. *oleracea* leaves were dipped in distilled water containing the spreading agent only. The numbers of cocoon formation of *C*. *plutellae* were recorded daily until all the cocoon of *C*. *plutellae* was recorded. The numbers of adult emergence of *C*. *plutellae* were also recorded based on the collected cocoon.

2.6 Statistical analysis

The insecticide bioassay data were analyzed by probit analysis (Finney, 1971) using DPS data processing system (Tang and Feng, 1997). The significance of difference for cocoon formation and adult emergence was calculated by *t*-test or Duncan's multiple range test (Tang and Feng, 1997). The percentage of cocoon formation of *C*. *plutellae* = (cocoon number/number of tested larvae DBM) × 100. The percentage of adult emergence of *C*. *plutellae* = number of emerged adult of *C*. *plutellae*/number of cocoon of *C*. *plutellae* × 100.

3 RESULTS

3.1 Toxicity of insecticides to DBM and *C*. *plutellae*

The susceptibility to fipronil was far higher than that to avermectin in the adults of DBM and *C. plutellae*. Besides, adults of DBM showed far lower susceptibility to the two insecticides than those of *C. plutellae* based on the mortality obtained by the dry film method (Table 1). When compared the LC_{50} values of the two insecticides obtained by leaf dipping method, in view of the overlap of 95% confidence limits (CL) of LC_{50} values, the susceptibility of 2nd larvae of DBM to the two insecticides was similar (Tables 2 and 3). The mortality of DBM larvae obtained by leaf dipping method was far higher than that of *C. plutellae* adults obtained by dry film method at the same concentration of avermectin, while far lower than that of *C. plutellae* adults obtained by dry film method at the same concentration of fipronil (Tables 2 and 3).

Table 1 Susceptibility to insecticides in the adults of *Cotesia plutellae* and DBM in Shangjie, Minhou, Fujian, China by using dry film method

Insecticides	Adults of *C. plutellae*[a]		Adults of DBM[1]	
	Treated dosages ($mg \cdot L^{-1}$)	Mortality (%) (48 h)	Treated dosages ($mg \cdot L^{-1}$)	Mortality (%) (48 h)
Avermectin	9	76.7 ± 15.3	1 800	100
Avermectin	6	53.3 ± 11.5	1 200	50.0 ± 17.3
Avermectin	3	0	600	0
Fipronil	0.25	100	6.25	93.3 ± 5.8
Fipronil	0.125	90.0 ± 10.0	1.25	0

a: Each concentration was replicated three times, each with 15 individuals.

3.2 Cocoon formation and adult emergence when treated at the egg stages of *C. plutellae*

When compared to the control, the cocoon formation and adult emergence of *C. plutellae* reduced by 26.6% and 13.1% on average, respectively, when larvae DBM were fed on avermectin at the egg stage of the parasitopid; and by 76.9% and 53.1%, respectively when DBM larvae were fed on fipronil. Significant depressions on the parasitoid's cocoon formation when treated by the two insecticides, and on the parasitoid 's adult emergence when treated fipronil were found. However, there was no significant depression on the adult emergence of *C. plutellae* by avermectin treatment.

3.3 Cocoon formation and adult emergence when treated at the early and mid larval stage of *C. plutellae*

When parasitized DBM were fed on sublethal dosage of avermectin at the early larval stage of *C. plutellae* (*i.e.*, on the 3rd day), the percentage of cocoon formation of *C. plutellae* decreased markedly (inhibition rate = 22.8%). But no significant depression on cocoon formation of *C. plutellae* was found if the avermection treatment was used at the mid larval stage of *C. plutellae* (*i.e.*, on the 5th day). In addition, no significant depression on the adult emergence of *C. plutellae* was found when DBM larvae were treated with avermectiin on the 3rd or 5th day. Fipronil treatment displayed significant depression on the cocoon formation. The inhibition rate was 42.5% when the DBM larvae were treated with the insecticide on the 3rd day, and 18.5% when treated on 5th day. Meanwhile, significant depressions on the parasiotoid 's adult emergence were found when the DBM larvae were treated with fipronil at both early and mid larval stages of the parasitoid.

Fipronil treatment displayed sinificantly higher depression on the cocoon formation and adult emergence of *C. plutellae* than avermectin treatment when DBM were treated with avermectin or fipronil (Tables 2 and 3). The depressions on the cocoon formation when the two insecticides were applied at the parasitoid 's egg stage (Table 2) were significantly higher than those when applied in the parasitoid 's larval stage (Table 3). The depression of the two insecticides on the cocoon formation was significantly higher than that on adult emergence no matter that DBM were fed on the insecticides at the egg or larval stages of *C. plutellae* (Tables 2 and 3).

4 DISCUSSION

The susceptibilities to the two insecticides in *C. plutellae* adults were far higher than those in DBM adults based on our results obtained by dry method (Table 1). Avermectin and fipronil are thought to be effective insecticides to control the DBM in the field, and the recommended rate for field application is about 18 mg/L for avermectin and 25 mg/L for fipronil. In view of contact toxicity of avermectin and fipronil obtained by dry film method (Table 1), the control rate of avermectin for DBM in the field seemed to be low toxic to the adults of *C. plutellae* by contact action in the field. Different from avermectin, fipronil at the control rate was highly toxic to the adults of *C. plutellae* by contact action in the field. However, avermectin and fipronil ingested by larvae DBM were all highly toxic to the eggs, early or mid stage larvae of *C.*

Table 2 Cocoon formation and adult emergence of *Cotesia plutellae* when parasitized larvae of DBM were fed on insecticides on the first day after oviposition by *C. plutellae*

Insecticides	Experiment time	Toxicity regression equation for DBM larvae (leaf-dipping method)	Correlation coefficient	LC_{50} for larvae DBM[a] (95% CL) ($mg \cdot L^{-1}$)	Treated dosages (LC_{10})[b] ($mg \cdot L^{-1}$)	Cocoon formation of *C. plutellae*[c] (%)		Inhibition rate (%)	Adult emergence of *C. plutellae*[c] (%)		Inhibition rate (%)
						Control	Treatment		Control	Treatment	
Avermectin	Spring	4.11 + 1.69x	0.93	3.35 (3.18 – 3.65)	0.59	27.2 ± 7.28 a	17.5 ± 8.25 b	35.7	99.2 ± 3.88 a	85.9 ± 6.87 a	13.4
Avermectin	Autumn	4.07 + 1.84x	0.97	3.28 (2.69 – 5.60)	0.64	30.4 ± 5.68 a	25.1 ± 5.42 b	17.4	98.7 ± 4.04 a	86.2 ± 7.33 a	12.7
Fipronil	Spring	4.48 + 1.32x	0.97	2.48 (1.64 – 3.76)	0.28	27.2 ± 7.28 a	7.40 ± 2.85 b	72.8	99.2 ± 3.88 a	44.8 ± 12.6 b	54.4
Fipronil	Autumn	4.43 + 1.64x	0.98	2.20 (1.97 – 2.57)	0.37	30.4 ± 5.68 a	5.80 ± 6.24 b	80.9	98.7 ± 4.04 a	47.5 ± 11.5 b	51.9

a: The leaf-dipping method was used for bioassay of 2nd instar larvae of DBM. LC_{50} of DBM was calculated from the toxicity regression equation based on the mortality at 48 h after treatment.

b: At first, 20 2nd instar larvae of DBM as a group were fed on the leaves with insecticide treatment for 2 h at LC_{10} dosages (sublethal dosages for 2nd instar DBM). The 20 host larvae were then left to expose to parasitoid's oviposition for 8 h by a pair of pre-mated adult of *C. plutellae*. The total number of tested hosted larvae for each treated dosage was 100.

c: Values were means ± *SE* of 5 replicates. Means followed by different letters differ significantly between the control and the treatment based on *t*-test ($P \leq 0.05$). All of the original data was translated by arcsine transformation before *t*-test.

Table 3 Cocoon formation and adult emergence of *Cotesia plutellae* when parasitized host larvae were fed on insecticides on the third and fifth day after oviposition by *C. plutellae*

Insecticides	Toxicity regression equation for DBM larvae (leaf-dipping method)	Correlation coefficient	LC_{50} for larvae DBM[a] (95% CL) ($mg \cdot L^{-1}$)	Treatment time[b]	Treated dosages (LC_{10})[c] ($mg \cdot L^{-1}$)	Cocoon formation of *C. plutellae*[d] (%)	Inhibition rate (%)	Adult emergence of *C. plutellae*[d] (%)	Inhibition rate (%)
Avermectin	4.12 + 1.57x	0.99	3.62 (2.74 – 4.78)	Control	0.55	54.8 ± 4.45a		98.5 ± 0.00 a	
Avermectin			3.62 (2.74 – 4.78)	3rd day	0.55	42.3 ± 7.72b	22.8	94.3 ± 4.95 a	4.3
Avermectin			3.62 (2.74 – 4.78)	5th day	0.55	51.6 ± 7.55a	5.8	86.2 ± 4.09 a	12.5
Fipronil	4.10 + 1.98x	0.99	2.85 (2.64 – 3.49)	Control	0.63	52.5 ± 4.45a		97.2 ± 0.00 a	
Fipronil			2.85 (2.64 – 3.49)	3rd day	0.63	30.2 ± 6.13c	42.5	62.1 ± 8.23 b	36.1
Fipronil			2.85 (2.64 – 3.49)	5th day	0.63	42.8 ± 4.09b	18.5	50.7 ± 7.37 b	47.8

a: The leaf-dipping method was used for bioassay of 2nd instar larvae of DBM. LC_{50} of DBM was calculated from the toxicity regression equation based on the mortality at 48 h after treatment.

b: Four to five 2nd instar larvae of DBM were used to expose to oviposition by one pre-mated female adult of *C. plutellae*. 20 2nd instar larvae of DBM were needed. Then, the 20 DBM were fed on the insecticides on the 3rd and 5th day, respectively after the larvae were parasitized successfully by adult *C. plutellae*. 120 2nd instar larvae of DBM with six replications for each treated dosage were needed in total.

c: The host larvae were fed on the insecticide at LC_{10} dosages (sublethal dosages for 2nd instar DBM).

d: Values were means ± *SE* of 6 replicates. Means followed by different letters differ significantly between the control and the treatment based on Duncant's-test ($P \leq 0.05$). All of the original data was translated by arcsine transformation before Duncant's-test.

plutellae, because the cocoon formation or adult emergence of *C*. *plutellae* were inhibited significantly if the parasitized DBM larvae were fed on leaves treated with avermectin and fipronil, even at very low dosages (= LC_{10} to the host insects) (Tables 2 and 3).

The effects of the insecticides on cocoon formation and adult emergence of *C*. *plutellae* varied depending on different developmental stages of parasitoid. The cocoon formation of *C*. *plutellae* was inhibited if the parasitized DBM larvae were fed on leaves treated with avermectin when the immature parasitoids were at the egg and early larval stages, but no significant inhibition on cocoon formation of *C*. *plutellae* was found if the parasitized host larvae were fed on avermectin when the immature parasitoids were at the mid larval stage. It seemed that the tolerance of *C*. *plutellae* to avermectin at its mid larval stage might be higher than those at its egg and early larval stages. Perhaps, because the toxicity of the two insecticides decreased significantly on the *B*. *oleracea* leaf or metabolized in the host larva during this period, the depression of avermectin or fipronil at LC_{10} dosages on the cocoon formation was significantly higher than adult emergence in general (Tables 2 and 3).

The effects of the insecticides on cocoon formation and adult emergence of *C*. *plutellae* also varied depending on insecticide selection (dosage and chemical class). For instance, the cocoon formation of *Diadegma semiclausum*, a larval parasitoid of DBM, could be inhibited by avermectin when parasitized *P*. *xylostellae* were treated at low dosages (LC_{10} values for larvae DBM). Moveover, the adult formation was also inhibited by avermectin, when *P*. *xylostellae* were treated at high dosages (LC_{40}). On the other hand, treatment of DBM larvae with teflubenzuron showed little effect on the number of parasitoid cocoons formed and the number of adult parasitoids emerged (Iqbal and Wright, 1996). Significant depressions on cocoon formation of *C*. *plutellae* were found when the host insects were treated with methamidophos at LC_{34} dosage. However, there was no significant depression on the adult emergence of *C*. *plutellae* at this dosage (Lin *et al*., 2007). The toxicity of fipronil to *C*. *plutellae* was far higher than that of avermectin (in this study) and methamidophos (Wu and Jiang, 2004). In this study, no inhibitions on cocoon formation were found when parasitized DBM were treated with avermectin on 5th day, and no inhibitions on adult emergence were found when parasitized DBM were treated with avermectin on the 1st, 3rd and 5th day, respectively. However, both cocoon formation and adult emergence of *C*. *plutellae* were inhibited significantly when the parasitized DBM were fed on the leaves treated with fipronil at LC_{10} dosage to DBM on the 1st, 3rd and 5th day, respectively (corresponding to the egg, early and mid larval stages of the parasitoids). In addition, corresponding to the insecticide toxicity, fipronil exhibited significantly higher depression on the cocoon formation and adult emergence of the parasitoid than avermectin. The fact indicated that fipronil might produce more serious damages to the immature *C*. *plutellae* than avermectin in the field application. Our results showed that avermectin and fipronil, even at very low levels (LC_{10}) to DBM larvae, might still be severe for the eggs or early larvae of *C*. *plutellae* in this study. The facts should be considered in risk assessment of insecticide to non-target insects.

The insecticides ingested by host insect inevitably create a challenge to endoparasitoids that leads to endoparasitoid's insecticide resistance. Different from pest insects, the *C*. *plutellae* living inside its host larvae did not face directly to insecticides in the field because of being protected by the host larvae. Thus, the parasitoids are not subjected to the same selection pressure as their host insects. Survival of the parasitoid could occur if the parasitoid was contacted with insecticides at a low dose or for a short time, or came from neighboring unsprayed vegetables and weeds, or the host was parasitized successfully before spraying. The facts might result in a low increase level of insecticide resistance in parasitoids. The insecticides ingested by host insects might be an important selection factor for the evolution of endoparasitoid's insecticide resistance in addition to contact with the insecticides directly in the field. In this study, endoparasitoid was selected during the egg and larval stages with the two insecticides. This phenomenon as observed in our study could be a possible path for endoparasitoid's resistance development.

Almost every insecticide applied in field was found in DBM. In certain parts of the world, economical production of crucifers has become almost impossible because of its resistance to insecticides and the resultant control failure. A coordinated resistance management program needs to be implemented with the involvement of pesticide industry, local pesticide regulatory authorities, scientists and farmers. The judicious use of chemicals in conjunction with other control measures including biological control agents is the best way to manage DBM and other pests of cruciferous crops (Sarfraz and Keddie, 2005). However, resistance might be less common in natural enemies than in herbivores due to a variety of factors, including a generally lower detoxification capacity (lacking pre-adaptation), lower genetic variability (in response to pesticides) and the fact that they spent less time on

treated habitats (Croft and Strikler, 1983; Tabashnik, 1986). The evaluations of insecticide toxicity to parasitoids were mainly focused on the lethal effects. However, sublethal insecticides also showed significant effects on the development, production and behavior of parasitoids (Gu and Waage, 1990; Desneux *et al*., 2007). Because a natural enemy would rarely survive at most effective control doses for the host, in particular in the case of parasitoids (Croft and Strikler, 1983; Wu and Miyata, 2005), insecticide selection (type and dosage), application timing and the establishment of refuges (the keep of weeds outside of the fields) would be very important in the integration of chemical and biological control.

ACKNOWLEDGEMENTS We thank Lin YW, graduated student of Fujian Agriculture and Forestry University, for his help in collecting the insects from the fields. This work was supported by China-Japan Cooperation Program, the Ministry of Science and Technology, China (2005DFA30440) and National Natural Science Foundation of China (30771413).

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亚致死剂量阿维菌素和氟虫腈处理小菜蛾对寄生蜂菜蛾绒茧蜂生长发育的影响

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摘要：分别在小菜蛾体内的菜蛾绒茧蜂处于卵期、早期幼虫和中期幼虫时，饲喂小菜蛾 2 龄幼虫亚致死剂量（= LC_{10}）的阿维菌素和氟虫腈，研究上述杀虫剂处理对寄主体内菜蛾绒茧蜂结茧率和羽化率的影响。结果表明：在菜蛾绒茧蜂处于卵期、早期幼虫和中期幼虫时，饲喂小菜蛾 LC_{10} 剂量阿维菌素处理的菜叶后，菜蛾绒茧蜂的结茧率分别下降 26.6%，22.8%和 5.8%，饲喂小菜蛾 LC_{10} 剂量氟虫腈处理的菜叶后，菜蛾绒茧蜂的结茧率分别下降 76.9%，42.5%和 18.5%。上述阿维菌素处理对菜蛾绒茧蜂成虫羽化率影响不显著，但上述氟虫腈处理可显著抑制菜蛾绒茧蜂成虫羽化率，在菜蛾绒茧蜂处于卵期、早期幼虫和中期幼虫时，饲喂小菜蛾 LC_{10} 剂量氟虫腈处理的菜叶可导致菜蛾绒茧蜂成虫羽化率分别下降 53.1%，36.1%和 47.8%。结果显示，即便是对寄主小菜蛾幼虫很低的剂量（LC_{10} 剂量）也会显著危害小菜蛾幼虫体内的菜蛾绒茧蜂的生长发育。此外，饲喂小菜蛾幼虫亚致死剂量杀虫剂对菜蛾绒茧蜂生长发育的影响与杀虫剂种类及蛾绒茧蜂发育阶段有关。

关键词：菜蛾绒茧蜂；阿维菌素；氟虫腈；亚致死剂量；结茧率；羽化率

中图分类号：Q964　　**文献标识码**：A　　**文章编号**：0454-6296(2008)03-0269-08

（责任编辑：袁德成）